

NASA Contractor Report 145381-1

STUDY ON

Utilization of Advanced Composites in Commercial Aircraft Wing Structures

EXECUTIVE SUMMARY



I. Frank Sakata and Robert B. Ostrom

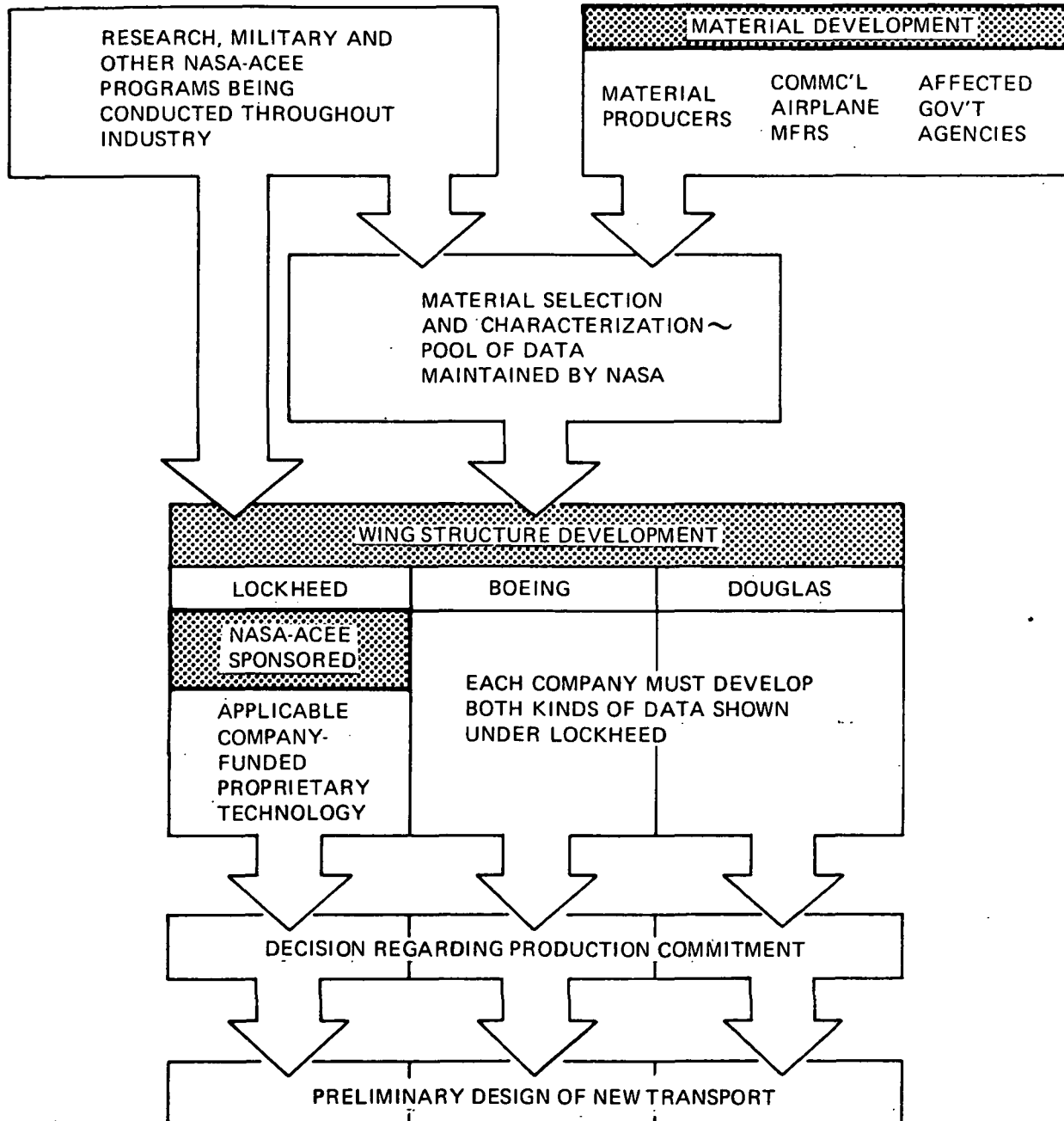
LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

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National Aeronautics and Space Administration
Langley Research Center • Hampton, Virginia

OVERVIEW OF RECOMMENDED PROGRAM
(SHADED ITEMS ARE DISCUSSED IN REPORT)



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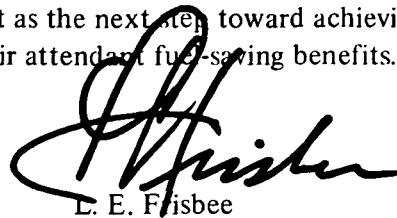
FOREWORD

The Lockheed-California Company has completed a study for NASA/Langley wherein a plan for the use of composites was developed. The aim of this plan is to assist the various aircraft manufacturers in reaching that degree of technology readiness which would enable them to use advanced composite materials in wing primary structure applications. Implementation of a plan, such as this, will be necessary if we are to introduce new lightweight and more energy-efficient structures into airline service.

In our view, the first opportunity for extensive application of composite materials in wing primary structure could occur with the introduction of a new long-range subsonic transport entering service in the early 1990s. Design of this aircraft would start in the 1985-1990 time frame. Consequently, the aircraft industry should take advantage of this intervening time period to develop advanced composite materials oriented toward improving their fabrication costs and material properties. Starting immediately, we believe NASA should take the lead in an effort which would bring material manufacturers and users together in a joint program devoted to improving current materials as well as developing new composite systems. In addition, we believe NASA should initiate programs with the three major aircraft manufacturers to develop technology and data relative to the incorporation of composite wing primary structure in future commercial aircraft.

The development program recommended by Lockheed does not involve building and flying a composite wing. It does, however, include an extensive design, analysis, fabrication, and ground test effort. This effort is necessary to acquire sufficient engineering and manufacturing data to reduce the risk to an acceptable level and thereby provide Lockheed and others with the option of proceeding into a 1985-1990 transport design incorporating a composite wing structure.

I personally endorse this plan and view it as the next step toward achieving new lighter-weight aircraft structures and their attendant fuel-saving benefits.

A handwritten signature in black ink, appearing to read "L. E. Frisbee", is positioned above the printed name.

L. E. Frisbee

Vice President & General Manager
Engineering & Operations

STUDY ON UTILIZATION OF ADVANCED COMPOSITES IN COMMERCIAL AIRCRAFT WING STRUCTURES

INTRODUCTION

NASA's Aircraft Energy Efficiency (ACEE) program is designed to improve the fuel-efficiency of commercial airplanes. One element of the program is to accelerate the introduction of high strength-to-weight ratio advanced composites materials into aircraft structures. The particular subelement discussed here is the development of technology for composite material primary wing structure.

A study was performed at the Lockheed-California Company to formulate a plan whereby commercial transport developers could accomplish the transition from construction materials currently used for aircraft wings to the extensive use of composites in time for applications in the 1985-1990 time period. The study defined the ingredients of the development needed to provide airline transport manufacturers with the option to commit to the use of advanced composites in wing structures of future production aircraft. All engineering and manufacturing disciplines normally involved in the design, development, and production of new aircraft were studied. Detail descriptions of the wing development plan and supporting data are presented in Reference 1.

The plan which the study produced defines two separate development programs, both of which should start immediately:

- A material development program; a joint government-industry effort involving manufacturers and material suppliers.
- A wing structure development program, to be done by each of the three major commercial transport manufacturers, Boeing, Lockheed, and McDonnell Douglas.

It is Lockheed's belief that these programs will assist commercial transport manufacturers in reaching a level of technology readiness where the use of composite materials is a cost-competitive option for a new aircraft production program.

Although several advanced composite structures programs now exist in industry, a program to expand the data bases being generated is needed before the materials can be confidently applied to primary wing structures of commercial aircraft.

It's recognized that wing structures can be made of current composite material systems, however, it is also recognized that these material systems have shortcomings, particularly in the areas of fabrication cost and material toughness. Improvements are both desirable and feasible.

Studies on the use of composites in aircraft secondary and medium-primary structures now sponsored by NASA's ACEE program at the three major commercial transport manufacturers are shown in Figure 1. These programs are already helping to

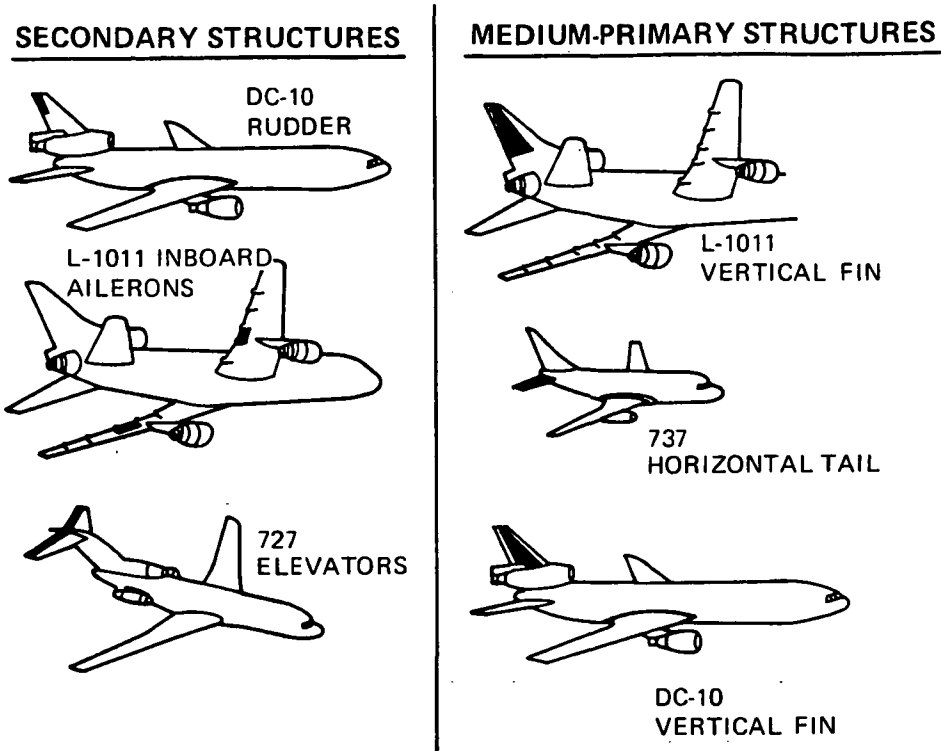
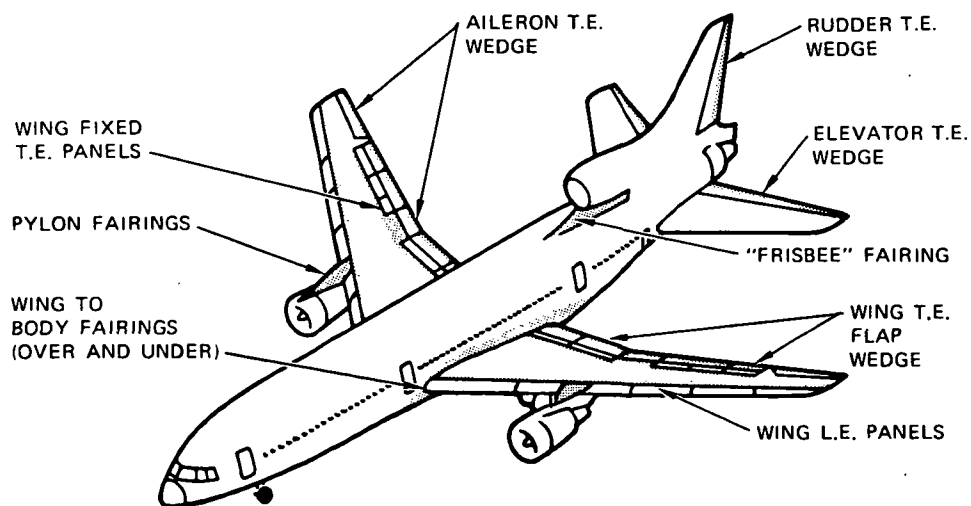


Figure 1. NASA-ACEE composites programs at major commercial aircraft manufacturers

prepare the industry to use composite materials in airline airplanes. Figure 2 illustrates one type of composite material which is already committed to production on



TOTAL KEVLAR-49 COMPOSITE APPLICATIONS — 1134 kg (2500 lbm)
WEIGHT SAVED — 365 kg (805 lbm)

Figure 2. Current use of Kevlar on Lockheed's L-1011

an aircraft now in service -- the use of Kevlar on the L-1011. Graphite/epoxy materials are planned to be used extensively on Lockheed's L-1011 in the near future as shown in Figure 3. It is expected that, as a result of the programs indicated on Figures 1, 2, and 3, Lockheed will be using large amounts of composite materials in commercial aircraft in the pre-1985 period.

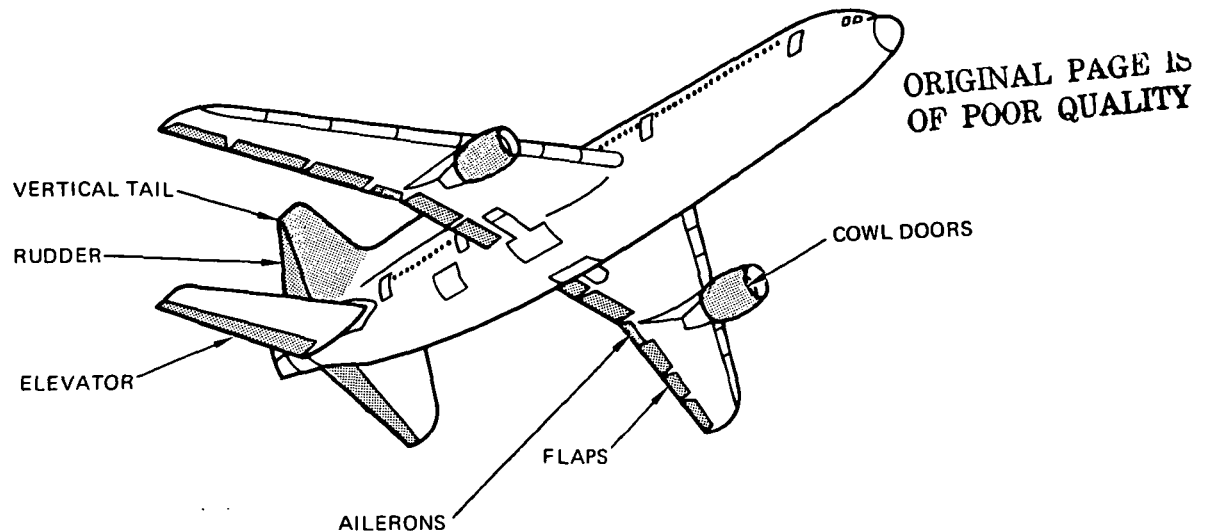


Figure 3. Potential application of graphite/epoxy to Lockheed's L-1011

Extensive application of composite materials in wing structure of commercial transport aircraft requires industry-wide development of a technology base which will support design, manufacture and operations. Much of the required technology and experience is not readily transferable from one company to another. Consequently, each of the major commercial transport manufacturers will require similar development efforts. The most appropriate form for the composite wing technology development program is one which assists each manufacturer (supplements in-house efforts) in developing the data it needs to commit to production of composite wing structures: the establishment of a technology base through analytical studies, manufacturing development and development testing.

Development of the data base must include extensive ground testing of full-scale subcomponents. Flight programs of a complete or partial composite wing box for a commercial transport are not necessary ingredients of a composite wing technology development program. Of prime concern is the demonstration of the feasibility and the cost-effectiveness of incorporating composite wing structure in future aircraft.

Once a sufficient data base exists to convince a company that benefits of utilizing composite wings can be achieved with acceptable risk, it can proceed with the production, certification and marketing of new aircraft. The production program would include the normal design, development, and flight test programs. Airlines acceptance and FAA certification would be addressed in the fashion associated with the introduction of any new aircraft.

TIMING

Based on world air traffic demand and airline financial conditions, it is expected that new equipment buys will occur in the early 1980's and again in the 1990's, as shown in Figure 4. The impetus for the first buy is 1) recovery to a favorable airline financial condition, and 2) the need to replace the aging fleet of narrow-body

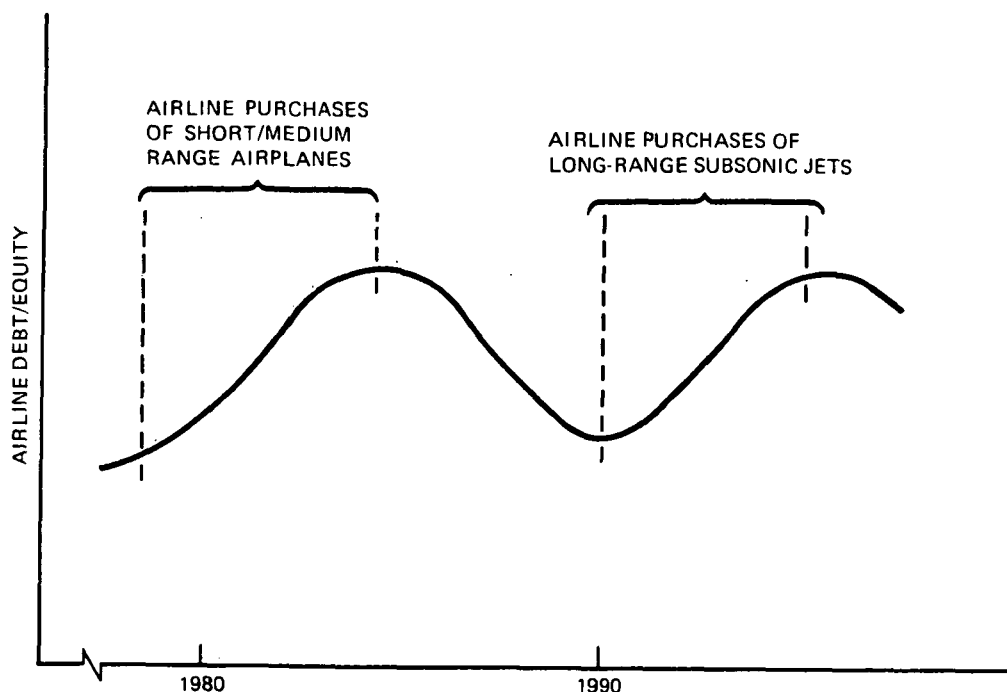


Figure 4. Marketing study results

transports, such as 707's and DC-8's with short-to-medium range 200-220 passenger equipment. These needs can be fulfilled by derivatives of current wide-body transports or by new aircraft whose design must start at once. However, the near-term application of advanced composite materials to primary wing structure is unlikely since the necessary technology is not yet available.

Looking to future buys, the next generation of advanced-technology long-range transport aircraft are expected to occur in the late 1980's or early 1990's. (This timing will coincide with financial recovery from the preceding buy.) The design of airplanes to meet this need will start around 1985. With a concentrated effort, the technologies for applying advanced composites to primary wing structures can be made available by then. The recommended plan as shown in Figure 5 reflects this timing.

Large benefits will result from the use of composite materials only if used extensively, which means that they must be applied at the onset of development. To apply composites on a substitution basis (i.e., substitute composite for metal without changing component size) will yield a limited total weight reduction and its

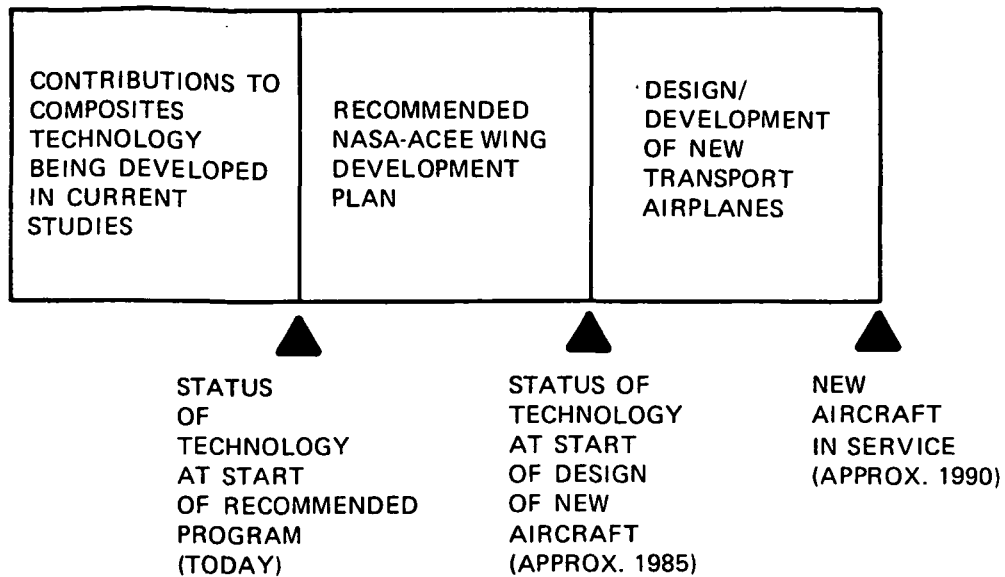


Figure 5. Timing of plan

corresponding fuel saving. Figure 6 shows that even for a 25 percent weight reduction in wing structure, only 3 percent fuel saving is expected during a typical mission. Furthermore, substituting composites for aluminum late in an airplane's production life would be uneconomical because of the large nonrecurring cost.

	WEIGHT SAVING	FUEL SAVING
WING SUBSTITUTION ONLY		
WING	25%	
AIRFRAME (INCLUDES WING)	8%	
TAKEOFF WEIGHT	3%	3%
ALL NEW/RESIZED DESIGN		
AIRFRAME (INCLUDES WING)	33%	
TAKEOFF WEIGHT	18%	18%

Figure 6. Benefits of advanced composites

However, in a new design, full use of the weight reducing potential of a new material can be exploited. For a given mission (payload, speed, distance), a lighter wing structure would mean a lower takeoff gross weight, which in turn would mean that the wing, tail, engines, etc., can all be smaller. The result of weight compounding in a new design is shown in the figure as an *all new/resized* airplane. The figure shows that if the total airframe weight can be reduced as much as 33 percent, fuel-saving of 18 percent is possible.

Gains attributable to the use of advanced composite materials are encouraging. However, many technologies and data now being pursued in existing programs must be developed further before confidence is at a level where composite materials represent a viable alternative to metals for primary wing structures of a commercial transport aircraft.

The recommended composite wing development program plan which Lockheed feels is necessary for it to achieve technology readiness, at an acceptable level of risk, is illustrated in Figure 7. Indicated on the figure are the key milestones and the program interrelationships. The plan reflects the timing factors, the plan philosophy, as well as the essential technology development.

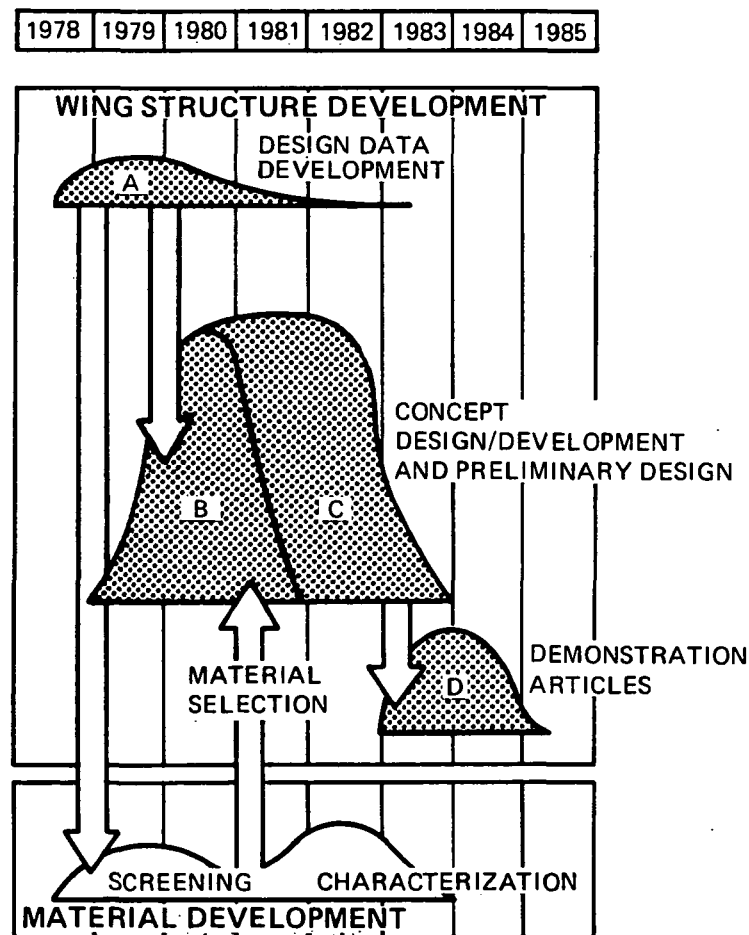


Figure 7. Recommended plan

The recommended material development employs the cooperative industry-wide effort to define the requirements for the improved material system, to plan and coordinate its development and evaluation, and to characterize its behavior.

The recommended wing structure development program embodies engineering and manufacturing studies, manufacturing development and development testing. The strong interrelationship between the concepts design/development and preliminary design are emphasized by showing the two linked together in one bubble in the figure. Details were studied during the plan development which enabled planners to make a fairly accurate estimate of the resources that will be needed; these are grossly indicated by the relative size of the bubbles in the figure. Full consideration was given to technologies expected to be available from other ACEE programs, the military programs, and company-funded research.

MATERIAL DEVELOPMENT

A key factor in any new aircraft production program is the selection of materials. While current composite materials could be used for a wing, these materials will be 20 years old by 1986. The current materials are deficient in terms of processing cost, mechanical property scatter, ductility and toughness, flame resistance, and durability. A new improved material system is needed. The major suppliers are continually developing improved materials. (It is also anticipated that significantly improved metals will be available by 1985, which might make it difficult for composites to compete.)

With readiness to commit targeted at 1985, there is time to develop a new material system for design of a new wing. A coordinated industry-wide effort is recommended to ensure that the improved material will be ready in time for application to primary wing structure of the next generation of commercial transports, and to prevent duplication and dilution of the material development effort.

There is also a need for multiple material sources which are capable of providing materials which are interchangeable on a ply-by-ply basis. A proprietary sole source material procurement environment represents an intolerable vulnerability for a company embarking on a billion dollar production program.

The schedule for the material development effort is shown in Figure 8. The program extends over 69 months. The material selection target date is at the end of 1980. This will permit incorporation of a new material system into the wing structure development program during preliminary design. It also affords sufficient time for developing mechanical property design data for a production commitment in the 1985-1986 time period. The material development program is described below.

Task A – Establish Industry Standards

A group of key personnel representing the government, materials suppliers and airline transport manufacturers will establish industry standards for materials,

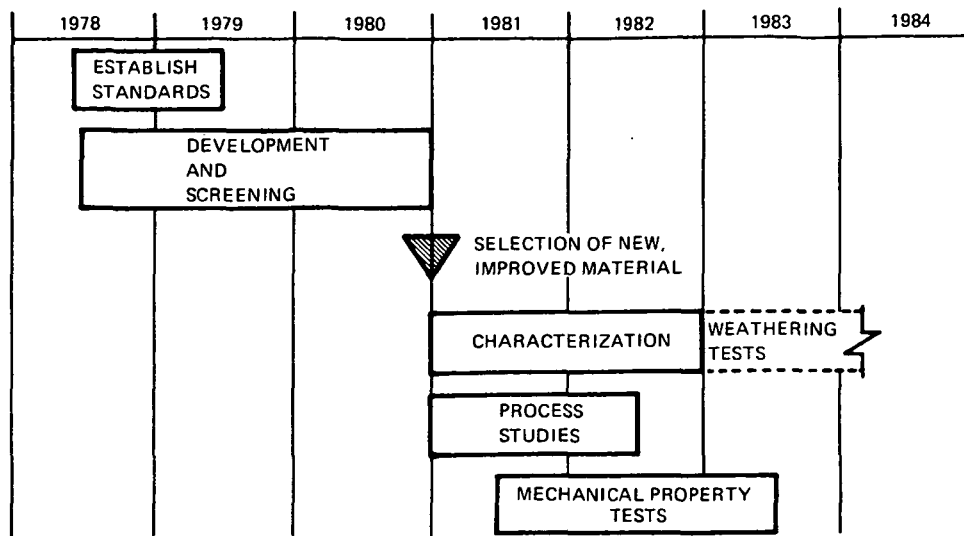


Figure 8. Recommended schedule for material program

processes, and test methods applicable to subsonic commercial transport aircraft. Their efforts will be guided by design criteria which meanwhile will be generated in the wing structure development program of each company, as shown in Figure 7. This work should be done under NASA leadership. Then, development by suppliers and evaluation by users can be done in consonance with target specifications.

Task B – Material Development and Screening

Material development by suppliers and evaluation by user will be carried out. Initially, to take full advantage of current material technology, the development of improved prepregs will be limited to resins and graphite fabrics that are commercially available. Those which show the most promise to provide solutions for the processing and functional problems encountered with currently used materials will be selected. The recommended target material characteristics are listed in the following table. It is anticipated that each material element change will result in reduced production processing cost and improvement of properties, quality level and consistency of the cured laminates. Candidate materials will be screened based on applicable trade-off studies, leading to the selection of the most promising material system.

Material Element	Target
■ Fiber (Typified by T300)	■ Improved base fiber – Advanced T300 or equivalent: ● more uniform size ● improved chemical stability ● minimized fiber defects

Material Element	Target
■ Fiber finish (Typified by Union Carbide 309 epoxy solution coating) ■ Reinforcement form (Typified by non-woven tape) ■ Resin type (Typified by 5208 epoxy) ■ Prepreg (Typified by T300/5208 material system)	■ High, stable fiber-resin bond ● better matrix adhesion for improved delamination resistance ■ Noncrimped fabric-unidirectional: ● simplified layup and processing ● improved tolerance to manufacturing processes ● reduced frequency of unacceptable prepreg defects ● better fiber spacing, collimation, alignment control and resin distribution ■ Improved, low flow and tough resin: ● simplified processing ● improved ductility and toughness ● better impact and flaw resistance ● reduced cure temperature ● improved flame resistance ■ Net prepreg resin content with above material element improvements: ● bleeding/prebleeding eliminated ● minimized property scatter ● maximized material forgiveness ● improved stress distribution, fatigue and impact resistance

Task C – Material Characterization and Substantiation

A comprehensive test program will be conducted in which the capabilities of the promising material system to meet all design and manufacturing conditions will be validated in the laboratory. These laminate tests include:

- Static mechanical properties
- Fatigue properties
- Flammability, smoke toxicity

- Environmental – accelerated weathering – laboratory
- Environmental – outdoor weathering
- Environmental cycling – laboratory

Appropriate number of test specimens, test variables, and types of tests will be included to verify the processing, mechanical properties, and fatigue properties of the selected material system.

Task D – Material and Process Variables Effects

To establish tolerable limits on variables in material and process specifications, the effects of these variables on finished composite properties will be investigated. Included are:

- Fiber/fiber batch variations
- Fiber/fabric finish batch variations
- Resin/prepreg batch variations
- Storage and aging time variations
- Layup – fiber pattern variations
- Cure process variations

The effects of variables on laminate properties will be established through mechanical tests of coupons including interlaminar cleavage, thermal analysis, and chemical analysis.

Task E – Mechanical Property Tests

Mechanical property values for structural design will be developed through static and fatigue tests of coupons considering appropriate test variables. Ply-level lamina tests will be used for determination of material strength and stiffness. Laminate tests on both notched and unnotched specimens will be used to verify predicted laminate strength and notch effects. Pin bearing tests will be conducted to determine laminate bearing strength. In addition, spectrum fatigue tests are specified for verification of the design strain level. These data will be prime inputs to the design data base.

Cost

The material development program will require a total government/industry effort of 115 man-years spread over several years. The distribution of this effort is shown

on the bottom of Figure 7. The early portion of this part of the plan will culminate in the selection of a material at the end of 1980, and the remaining portion of the program is devoted to characterization of the selected material system.

WING STRUCTURE DEVELOPMENT

Advancement of technology for production of composite wing structures for future transport aircraft requires industry-wide development of a technology base which will support design, manufacture and operations. Such a data base must include basic data on composite material response characteristics; analysis methods and development tests with which to evaluate structural concepts and manufacturing approaches; quality assurance procedures; valid cost data; and compilation and documentation of the data base.

Reliable analysis methods are essential for effective application of composite material to wing structures. The wing is highly loaded. Its structural integrity is vital. Composites offer significant weight savings if their properties can be exploited effectively. For example, the industry is only beginning to exploit the post-buckling regime of composite structure as it is in metals. Analysis methods must be developed and substantiated for predicting: static strength under combined loading, initial-buckling and post-buckling strengths, effects of normal and inplane loads and deformations, fatigue life, and damage tolerance and residual strength.

A major objective of the technology development will be the development of guidelines, data and handbooks necessary to support a large design force. These must include composite structures design handbooks and composite structure analysis methods manuals similar to those which are currently used to support the design of metallic structure.

The state of readiness for applying composite materials to wing structure of new aircraft must be advanced by each manufacturer. Both government sponsored and applicable company funded proprietary technology development is envisaged. The recommended wing structure technology development plan provides systematic development of the necessary data, capabilities and confidence for using composites in primary wing structures, starting now (in concurrence with the new material system development).

Initially, a minimal experimental program is planned to verify the strength and durability characteristics of the existing material systems (e.g., T300/5208 Gr/Ep) when subjected to the wing design environment. With this design data in hand, the concepts design/development effort can proceed to assess the relative merits of various concepts by sorting out the geometry sensitive parameters for design and manufacture of major wing structural components and to select the promising wing structural concepts. The promising concepts and the new material system (from the material development program) will then be brought into the preliminary design phase for further refinement and verification. This will be followed by fabrication and testing of large wing subcomponents to demonstrate technology readiness.

The recommended wing structure development program schedule is shown in Figure 9. The program extends over 87 months. For ease of discussion the program is divided into four tasks as shown in the figure and described below:

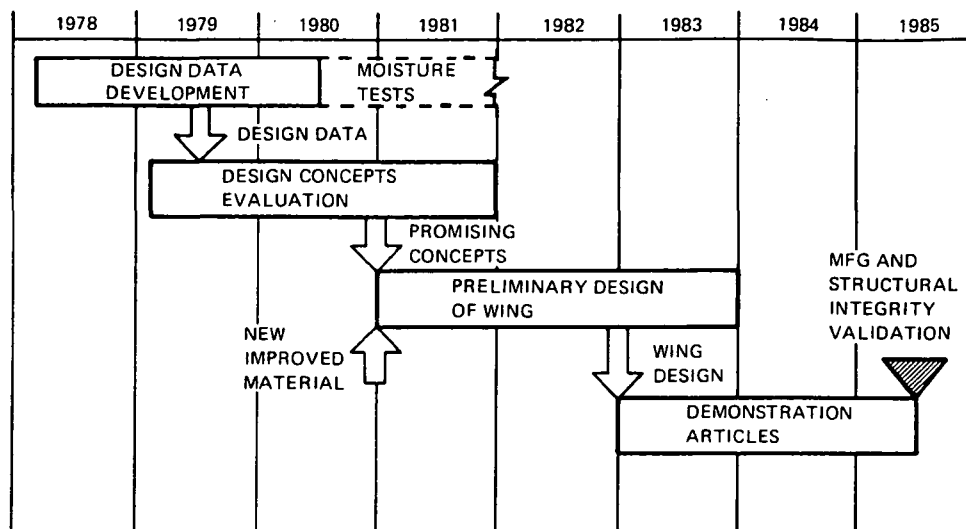


Figure 9. Recommended schedule for wing structure development program

Task A – Design Data Development

The design data being gathered in other ACEE programs must be expanded regarding the response of composite laminates when subjected to the wing design environment, particularly in terms of durability and damage tolerance. The wing structures of commercial transport aircraft are highly loaded and are subjected to large numbers of loading cycles, including significant ground-air-ground cycles. The capability of composite structure to withstand this loading environment, in conjunction with temperature and moisture, must be determined. Also, the effects of foreign object impact on thick laminates associated with wing surface structure must be determined. Such impact damage may not be visually detectable and thus may require the development of in-service NDI techniques. And, the effects of fuel on composite laminates must be determined. In summary, the design environment for composite wing structures must be defined, the effects on this environment must be experimentally evaluated, and appropriate design criteria established.

Data supplemental to that existing on T300/5208 graphite/epoxy will be developed in this initial task. This experimental effort will verify/determine the strength and durability characteristics of the T300/5208 material when subjected to wing design requirements. The tests will provide data to establish many criteria, such as design strain levels for laminates likely to be used in wings, and the effects of fatigue loading spectra, and variations of potential environments on design strain limits.

The tests span a period of five years. The majority of the tests will be completed in the first 27 months. Only moisture tests continue through 1983. Design data will

feed continuously to the concept design/development, and will influence standardization efforts in the material development part of the plan.

Task B – Design Concepts Evaluation

Concepts and arrangements for composite wing structures to best exploit the material must be developed. For example, the wing-fuselage interface, the main landing gear interface, and fuel tank containment must be studied. Aeroelastic characteristics of the wing will be important and may require tailoring the material and structure. Weight and cost data for various approaches must be assembled. Both, structural and manufacturing considerations must be included in these evaluations.

Promising concepts must be developed by tests. Significant or unique design problems must be experimentally evaluated. The required tests include: static and fatigue, including the effects of impact and of environment; damage growth; and residual strength. Surface panels, including panels with joints or access doors, spars, ribs and structural assemblies must be tested and compared with predictions to demonstrate that the structural integrity and durability requirements for the wing can be met.

Manufacturing development is configuration sensitive, and must be performed in conjunction with the structural design development effort. There is an appreciable scale-up required for wing production relative to sizes being considered in other ACEE programs. For example, the wing semispan will be approximately 30.5 m (100 ft), the wing box root chord approximately 6.1 m (20 ft), the box depth approximately 1.5 m (5.0 ft) at the root, and surface panel thicknesses will be greater than 1.27 cm (0.50 in.). Manufacturing concept development and tradeoff studies, and experimental fabrication and evaluation must be performed to obtain the producibility data needed to develop efficient structural configurations, and material processing and fabrication methods.

In this second task, various structural concepts will be studied for solving the many details contained in the design of a new wing with an advanced airfoil shape and active controls. Many details such as types of covers, spar or rib attachments, joints, control surface attachments, etc., are peculiar to wing design. Specimens of typical details will be designed and tested to study their behaviors; relative merits of various concepts will be sorted out.

Producibility studies will be made to establish practical and cost-efficient methods of fabrication of thick and large-sized wing components with camber and twist; and with varying thickness and cross-section.

A preliminary definition of the wing structure and design requirements will result from this planned 33-month effort. Promising design concepts will be defined through design-manufacturing studies, including an assessment of aeroelastic effects of the wing. Appropriate preliminary design bulletins and process specifications will

be developed. Structural elements will be fabricated using the developed processes. Development tests of key structural elements will define the most promising design concepts for a commercial transport aircraft wing structure.

Task C – Preliminary Design of Wing

A preliminary design of an entire wing structure of an advanced commercial transport is planned as the third task. The overall wing geometry might be very different from what will be considered for a new airplane several years later; however, it is essential that preliminary design of a wing be done in order to resolve all potential problems. The study will assure that all key issues are dealt with and that the response characteristics of an entire wing to typical loading environment are understood.

This work will expand and refine the concepts identified in Task B as promising; incorporate the new, improved material system; verify the design/manufacturing parameters; and validate approaches for selected subcomponents and major structural and systems interface designs, (for example, lightning strike protection and fuel containment). The manufacturing facilities plan and required resources will be updated reflecting the manufacturing methods projected for production of a composite wing.

A major objective of the manufacturing technology development, in addition to the development of manufacturing approaches, is the development of valid cost numbers for assessing production commitment. These must include both production and tooling cost estimates, and capital facility and equipment requirements, for alternative manufacturing approaches.

Development of quality assurance methods and data is also needed. These must cover the total manufacturing process, from material acceptance through final assembly inspection. Standards must be established for quality control of materials, processes and hardware. These will require development of improved inspection methods, improved test methods, process control methods, and acceptance criteria. The latter requires establishing the effects of defects on mechanical properties. Automated monitoring methods will be needed for inspection during laminate layup, and for cure-cycle control. A major need is the development of cost-effective nondestructive manufacturing inspection techniques; i.e., the development of automated techniques which can handle large, variable thickness, variable cross-section wing structure.

Candidate tooling approaches for wing production must be delineated, and the tooling and layup development needs must be identified. Again, the problems are size, laminate thickness, and the variation of thickness and cross-sections. Wing surface skins and stiffeners, for example, are tapered, cambered and twisted. These present added complexity in their effects on thermal expansion, shrinkage and warpage during the manufacturing process. Least-cost approaches for tooling and fabrication must be developed – starting with the most critical areas and ultimately including the complete wing. Advances in several fabrication technology areas are

required; e.g., automated layup and preforming, molding and automated shape forming, machining methods, and fastening techniques.

The composite wing structure must be inspected and repaired properly. Again, much work is being done in connection with other composite programs. For example, Boeing is presently under contract to NASA to develop NDI (nondestructive inspection) techniques, and the Lockheed-California Company is performing a NASA contract to develop practical repair methods. The suitability and effectiveness of techniques for inspecting thick laminates will have to be assessed. Fatigue and environmental durability of wing repairs must be verified.

A composite wing structure design that meets all the known requirements in terms of integrity and maintainability will be developed during this 36-month design-manufacturing-test effort. The manufacturing methods will be verified and production plans, including capital requirements, definitized. The design verification tests of wing covers, root joint, rib-cover interface, ribs and lightning protection system will be performed to provide the needed design-manufacturing data base and confidence to proceed with wing structure designs using extensive amounts of graphite/epoxy composites.

Task D – Demonstration Articles

Two demonstration articles will be designed and built for the final task, one of which will be structurally tested. This task will be conducted to assure that all problems will have been dealt with satisfactorily and that the necessary technology is in hand to proceed with confidence in a wing box design. Fabrication and testing of the demonstration articles over a 30-month period will involve:

- Demonstrating manufacturing procedures
- Gaining manufacturing experience
- Measuring response characteristics
- Assessing durability

A large section of skin with tapered stiffeners over 18.0 m (59.1 ft) long will be built (Figure 10). Its primary purpose is to demonstrate manufacturing capability. Although some automatic layup equipment will be in each company's inventory by 1983 in connection with other composite structures programs, it is assumed that the need for large autoclaves will be limited. Therefore, the length of the test article will be limited to the length of an existing large autoclave at the Lockheed-California Company, 18.29 m (60.0 ft). The wing cover segment will, by its configuration, provide a practical look at the task of constructing a large composite structure. The segment will validate such processes as: layup of very thick sections, cure cycles for structures with thick and thin sections, tooling for cocuring stiffeners to skin, thermal expansion effects between tool and part, and handling problems due to size

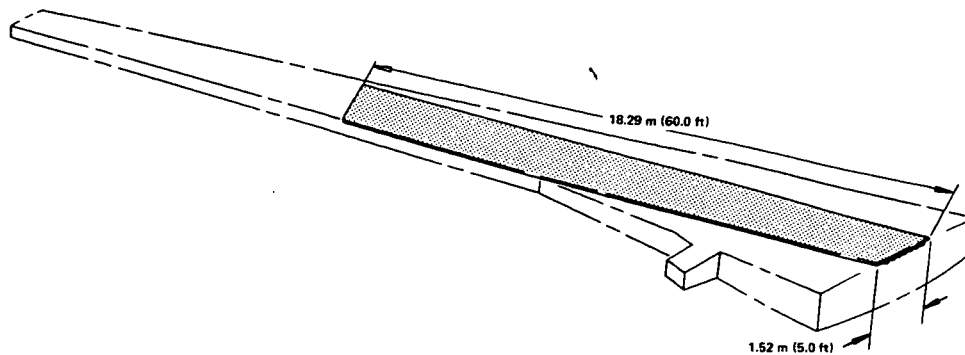


Figure 10. Process demonstration/validation panel

of part. Additionally the part will be used for verification of various inspection techniques including NDI. The completed article will be evaluated primarily by visual examination and dimensional inspection. Suspect areas may be sectioned and samples subjected to laboratory tests including chemical and micro analysis or mechanical strength and modulus tests.

The other demonstration article, is a wing box segment approximately 5.0 m (16.4 ft) long which will contain many structural details (Figure 11). In addition to demonstrating manufacturing capabilities, it will be used to test load-carrying properties, resistance to damage growth, response characteristics, and durability. The article will demonstrate solutions to unique problems such as the introduction of concentrated loads at hard points.

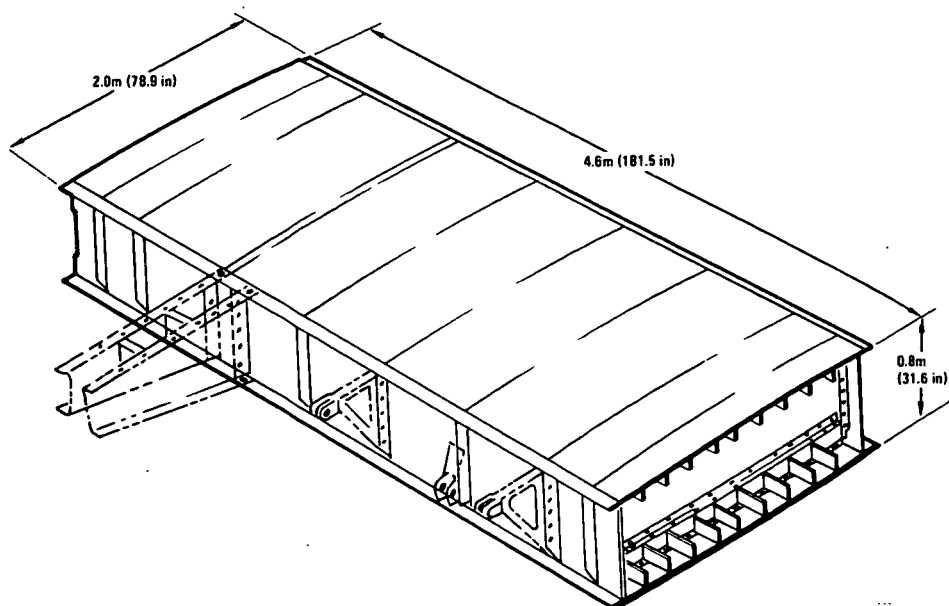
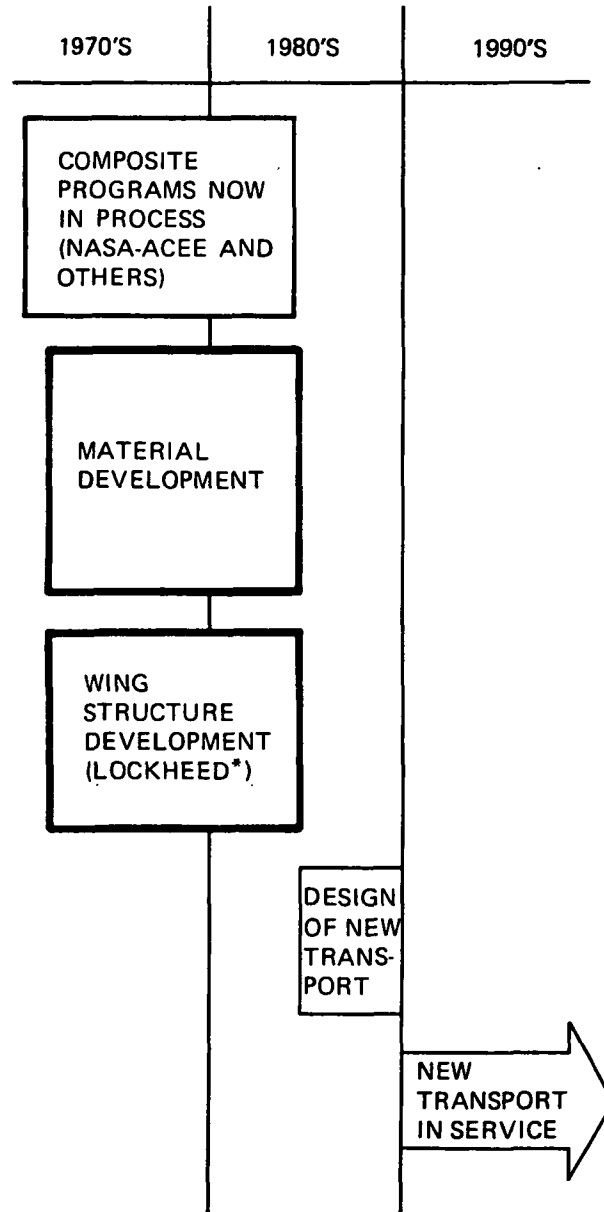


Figure 11. Representative wing box test specimen

Cost

The wing structure development program will require a Lockheed effort of approximately 460 man-years spread over 7-plus years. It would be expected that similar efforts would be required by the other major transport airframe manufacturers. A summary chart showing how the wing structure development plan relates to other associated programs is shown in Figure 12. The figure relates the wing structure



*SIMILAR PROGRAM AT OTHER COMPANIES

Figure 12. Recommended and associated programs

technology development to on-going composite programs and to the material development program, and targets completion for around 1985. The distribution among engineering, manufacturing and testing is shown in Figure 13. About half of the total effort will be devoted to developing manufacturing and quality assurance needs.

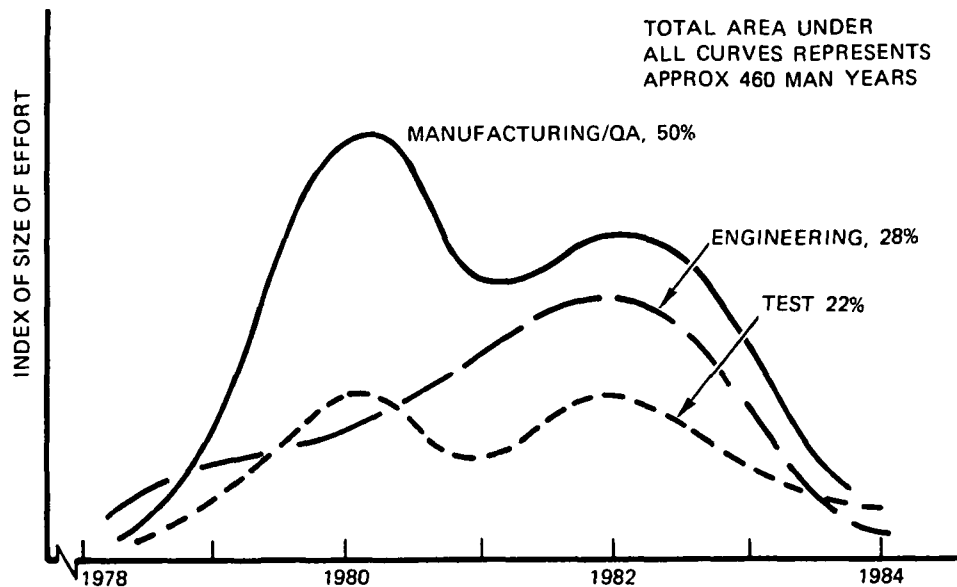


Figure 13. Distribution of effort among primary ingredients of wing structure development

CONCLUSION

It is Lockheed's belief that the development plan will assist commercial transport manufacturers in reaching a level of technology readiness where the use of composite wing structure is a cost-competitive option for a new aircraft production program. The recommended development effort consists of two programs:

- A joint government-industry material development program,
- A wing structure development program.

The material development program will result in a new, improved composite material systems that will lead to an efficient wing structure design. The wing structure development program will provide the technology and data needed to produce a cost-competitive advanced composite wing structure and to achieve certification of an aircraft employing such a structure.

The material development program is proposed as a joint effort between the manufacturers, the material suppliers, and the Government. Because of its general applicability to the design of composite aircraft structure, it is suggested that this effort be funded separately. The goal is a modified graphite/epoxy material system with improved characteristics that will meet engineering and manufacturing requirements, and at the same time, will not invalidate the existing graphite/epoxy data base. The material development must include consideration of modifications which will mitigate the electrical hazards problem associated with graphite fiber release in event of fire.

The planned wing structure development program encompasses engineering and manufacturing analytical studies; manufacturing development; and development testing to generate composite wing design data, to support concepts development, and for design verification. The program culminates in a manufacture and test demonstration of technology readiness using a representative (generic) wing box structure. The objective is to develop and demonstrate the technology needed for design and manufacture of composite wing structure which will meet durability and damage tolerance requirements. The development program is based on the belief that such a program will take the manufacturer as far as is practical towards developing the technology and data needed for production of composite wing structure. It is not felt, however, that a company, or the Government, can afford to fully exercise, in advance, the manufacturing scale-up efforts associated with building a complete wing structure. These must be addressed in normal company-funded production programs for new aircraft. Such a program probably would include the manufacture and test of two full-scale articles: a static and a fatigue/damage growth test article and a flight test article. It is believed that each manufacturer will require a similar composite wing development program to achieve technology readiness and an acceptable level of risk. At the same time, it is anticipated that each manufacturer's program will include some concept-peculiar aspects, reflecting differing philosophies, approaches, and operating procedures.

In recognition of the current uncertainties concerning the timing and funding of NASA's planned composite wing development program early initiation of two long-lead-time, high-priority technology development efforts are recommended:

- Development of a new, improved material system to be started immediately so as to provide a firm material base for the applications of composite primary wing structures. This material development effort should include the proposed efforts to alleviate the potential carbon fiber release hazard.
- Efforts be initiated in the near future to develop the data necessary to demonstrate the durability and damage tolerance characteristics of composite laminates when subjected to the wing design environment. These development efforts should include the definition of the wing design environment and the development of associated design criteria.

REFERENCE

Sakata, I. Frank and Ostrom, Robert B.: Study on Utilization of Advanced Composites in Commercial Aircraft Wing Structures – Final Report. NASA CR-145381-2, 1978.

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16. ABSTRACT A study was performed to plan the effort required by commercial transport manufacturers to accomplish the transition from current construction materials and practices to extensive use of composites in wings of aircraft that enter service in the 1990 time-period. The engineering and manufacturing disciplines which normally participate in the design, development and production of a new aircraft were employed to ensure that all of the factors that would enter a Company decision to commit to production of a composite wing structure were addressed. A conceptual design of an advanced technology reduced energy aircraft provided the framework for identifying and investigating unique design aspects. A plan development effort defined the essential technology needs and formulated approaches for effecting the required wing development. Presented are two separate programs: (1) a joint government-industry material development program, and (2) a task-oriented wing structure development program. This report presents a summary of the wing development program plans, resource needs and recommendations.			
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